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INFLUENCE OF COARSE-TEXTURED FERTILIZER BANDS, SURFACE RIDGES, AND VERTICAL STRAW MULCHES ON NITRATE LEACHING IN SOIL

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ABSTRACT

Because of concern that nitrogen fertilizers may contribute to pollution of water sources, treatments believed capable of reducing nitrate leaching were applied to boxes of Fort Collins clay loam. The treatments, applied in factorial combinations, were a coarse-textured band containing NaNO_3 versus a standard NaNO_3 band (200 kg N/ha), surface ridging versus no ridging, and a vertical straw mulch versus no mulch.

Rainfall, 13 to 14 cm total, was applied at two intensities: 1.43 and 9.63 cm/h. After drainage, the soils were sampled at 38 sites surrounding the bands and analyzed for nitrates. At the low rainfall intensity, only the coarse-textured band significantly reduced leaching. At the high rainfall intensity, significant reduction in leaching occurred because of the coarse-textured band treatment and an interaction between the vertical straw mulch and the standard band; the vertical mulch diverted water around and below the fertilizer.

An experiment with corn plants determined utilization of nitrates in coarse-textured bands. Treatments were a standard NaNO_3 band, a coarse-textured band with NaNO_3 , and no fertilizer. Moisture contents were maintained at field capacity. Plants were harvested at 2 and 4 weeks after emergence. Roots and tops were analyzed for total nitrogen content, and the soil was analyzed for nitrates. Results showed that, during the 4-week period, the coarse-textured band, while allowing some root uptake, significantly retarded nitrate leaching.

INTRODUCTION

The present national concern over environmental and ecological relations has focused attention on the quality of our water supplies. During the past several years, simultaneous increases in certain river nitrate levels and nitrogen fertilizer use point to agriculture as a potential major source of water pollution (2).² How-

ever, conclusions from numerous investigations of nitrate losses from soils and their contribution to water pollution are contradictory. Bower and Wilcox (1) noted a decrease over the past 30 years in the nitrate level of the Rio Grande. Others have shown that little nitrate leaches from the root zone of an actively growing crop (13) and that nitrates may take years to leach through the soil into the ground water (12). Conversely, significant nitrate concentrations were found in the drainage and runoff from certain irrigated western soils (4, 9).

Apparently, on a national basis, the fertilizer contribution to water pollution is unknown. However, it is obvious that at certain places and

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² Italic numbers in parentheses refer to items in "Literature Cited" at the end of this publication.

under certain conditions, nitrogen fertilizers contribute to local water pollution. When these conditions exist, cultural practices might be developed to retard nitrate leaching without adversely affecting crop yield. For example, Burns and Dean (3) in a laboratory study showed that a plastic trough placed under a NaNO_3 band effectively retarded nitrate leaching. Hayslip and Deen (8) reduced nitrate leaching in sandy soils and increased vegetable yields 40 percent by installing paper or plastic covers over fertilizer bands.

Since nitrates move with water, our knowledge of moisture flow can be applied to this problem. Several investigators (5-7, 10, 11, 15, 16) noted that textural discontinuities affect soil moisture movement. Water moving in fine-textured soil stops on encountering a coarse-textured layer; advancement proceeds only after moisture buildup and after tension reduction occur at the interface. A moisture front passes around, without entering, small coarse-textured obstructions and continues moving (6). Similarly, coarse-textured bands containing nitrogen fertilizers should initially delay water entry and fertilizer exit.

Nitrate leaching could be reduced further by controlling infiltration sites so that water is channeled away from fertilizer bands. The contribution of surface ridging, furrowing, etc. is obvious. Additional control may be possible by selective placement of vertical straw mulches. These mulches, i.e., chopped crop residues placed in vertical soil cuts, rapidly transmit water into the soil as long as the surface remains open. When placed between seed rows, the mulches could divert water away from the band and reduce the amount of water available for leaching nitrates. This laboratory experiment was initiated to determine the influence of surface ridging, vertical straw mulches, and coarse-textured bands on nitrate leaching.

EXPERIMENTAL PROCEDURE

Experiment 1

The treatments were vertical straw mulches (m_0, m_1), fertilizer bands (b_0, b_1), and surface ridges (r_0, r_1); the subscripts 0 and 1 respectively designate the absence or presence of the factor. All combinations of the three factors at two lev-

els result in eight different treatments. These treatments were installed in soil-filled boxes 8 by 60 by 100 cm. The soil, Fort Collins clay loam, was packed to a bulk density of 1.3 g/cm^3 . The average profile depth was 48.6 cm.

The coarse-textured band (b_1), 2.5 cm in diameter, consisted of gravel 2 to 2.5 mm in diameter. The band center was filled with 4.86 g NaNO_3 (200 kg N/ha based on 50-cm row spacing). The standard band (b_0) contained the same fertilizer treatment, but included no coarse-textured materials. The band was placed in the center of the box and 12 cm beneath the soil surface.

The vertical straw mulches, two to a box, were 2.5 cm wide, 20 cm deep, and 50 cm apart and were placed equidistantly from the band. The mulches were chopped Johnsongrass applied at a rate of 12.5 metric tons/ha. The surface ridges were 50 cm wide and 10 cm high at the center; the ridge center was directly above the band. Figure 1 shows a soil-packed box treated with a coarse-textured band, vertical straw mulches, and surface ridges (b_1, m_1, r_1).

Water was applied from one Sprayco Engineering³ nozzle 5B. The nozzle was 2.74 m (9 ft) above the soil surface; nozzle pressure was 0.42 kg/cm^2 (6 lb/in²). Average rainfall intensity was $9.63 \pm 0.77 \text{ cm/h}$; the average total rainfall was $13.36 \pm 0.80 \text{ cm}$.

Approximately 22 hours after rainfall, each soil box was sampled at the 38 sites surrounding the band. Each site was identified by Cartesian coordinates in centimeters, with the origin (0,0) at the center of the band. These soil samples were then analyzed for nitrate concentration by a modified Conway method (14).

The statistical design was a randomized, complete block of eight treatments and three replications; it was analyzed as a 2^3 factorial. Duncan's multiple-range test was used for mean separation. A separate analysis of variance was computed for each site.

Experiment 2

Experiment 2 was identical to experiment 1 except the average rainfall intensity and average

³ Trade names are used in this publication solely for the purpose of providing specific information. Mention of a trade name does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture or an endorsement by the Department over other products not mentioned.

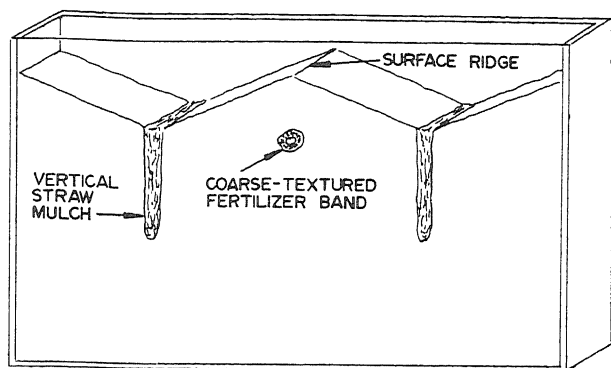


FIGURE 1.—Soil-packed box treated with a coarse-textured band, vertical straw mulches, and surface ridges ($b_1m_1r_1$).

total rainfall were 1.43 ± 0.18 cm/h and 13.85 ± 0.99 cm, respectively. The rainfall intensity was decreased by raising the nozzle to 3.96 m (13 ft) above the soil surface, increasing the nozzle pressure to 0.53 kg/cm² (7.5 lb/in²), and spraying 15 s/min. To achieve the 15-second interval, two 45° sectors were cut from a disk which rotated beneath the nozzle at 1 r/min. When the solid portion of the disk was beneath the nozzle, the water was channeled away to prevent overflow or splash onto the boxes.

Experiment 3

This experiment concerned plant utilization of fertilizer in coarse-textured bands. Eighteen boxes, 8 by 25 by 40 cm, were filled to 35-cm height with Fort Collins clay loam; the bulk density was 1.3 g/cm. 'Golden Bantam' hybrid cross sweet corn was planted four seeds per box at 5-cm depth. Fertilizers, when added, were banded 5 cm beneath and 5 cm to the side of the seed. The band contained NaNO₃ at the rate of 225 kg N/ha (200 lb N/acre). A mixture of KH₂PO₄ and KCl was also added to the band to give 39.2 kg P/ha (35 lb P/acre) and 187 kg K/ha (167 lb K/acre). The boxes were placed in a growth chamber with daytime temperature set at 28.9° C and nighttime at 23.3° C; the day length was 13 hours. Water content was maintained at field capacity by weighing the boxes every other day and adding water equal to the lost weight.

Six boxes contained coarse-textured bands, six were treated with standard bands, and six were not fertilized (check). Corn seedlings were thinned to two per box. Three boxes of plants in each treatment were harvested 2 weeks after

emergence and three boxes, 4 weeks after emergence. Tops and roots were separately harvested, dried at 65° C for 24 hours, and analyzed for total nitrogen content. In addition, the soil from each box was sampled at 4, 8, 12, and 16 cm, directly beneath the band, and analyzed for nitrates. The sampling sites were identical for the check treatment.

The statistical design was a completely randomized block with three replications. An analysis of variance and the associated *F* test were used to detect significant differences. Duncan's multiple-range test was used for mean separation. Results from each harvest were analyzed separately.

RESULTS AND DISCUSSION

Table 1 shows the average nitrate concentrations at sites where at least one treatment variable resulted in significant differences. Every site of significant difference was adjacent to or directly beneath the band. Table 2 shows the significance levels and the treatments responsible for these differences.

Tables 1 and 2 show that the coarse-textured band was the dominant factor influencing nitrate concentration. With few exceptions, treatments which included a coarse-textured band effected considerable reduction in nitrate leaching. The exceptions occurred at sites adjacent to the coarse-textured band; i.e., 0,—2; 2,0; and —2,0. The coarse-textured band radius was 1.25 cm; the radius of the sampling tube was 0.5 cm. Obviously, samples from these adjacent sites contained part of the coarse band, since the band center was at 0,0. Apparently some of the nitrate had spread through the band.

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tion of rainfall. Consequently, water was not funneled around and below the bands, but moved down into the profile almost as a level or slightly undulating front; thus, only the coarse-textured band significantly retarded nitrate leaching.

Table 3 shows the influence of the coarse-band treatment alone on nitrate concentration. Only sites of significant differences are shown; these were directly beneath the band. At low-intensity rainfall, differences as great as 2,350 parts per million NO_3^- -N attest to the effectiveness of coarse-textured bands in reducing nitrate leaching.

At high-intensity rainfall, 11 sites beneath the band showed significant differences because of the band treatment (table 2). In addition, some sites showed significant differences because of the mulch, the interaction of mulch with band, or a combination of both treatments.

Where interactions exist, main effect interpretations must be in terms of their response to the other involved factors. Table 4 shows the fertilizer band-vertical straw mulch (BM) interaction sites, average nitrate concentrations resulting from various BM combinations, and mean separation of those combinations. These data show

that the interactions are "change of rate" responses. At sites (0,—2), (0,—4), and (0,—6), the vertical straw mulch (m_1) shows the greatest decrease in nitrate concentration going from the standard fertilizer band (b_0) to the coarse-textured fertilizer band (b_1); at sites 0,—20 and 0,—24 the trend is reversed; the greatest decrease is found without the mulch (m_0). Since, in each case, there is no significant difference between combinations containing the coarse band (b_1), the interactions result from the differential response of the mulch treatments (m_0, m_1) to the standard band (b_0). Apparently, the coarse-band effect is not significantly influenced by mulch treatments.

Figure 2 shows the plot of average b_0m_0 and b_0m_1 nitrate concentrations (high-intensity rainfall) at depths directly beneath the site of fertilizer placement. Above 12 cm, the standard band-vertical mulch combination (b_0m_1) resulted in the highest nitrate concentrations; below 12 cm it gave the lowest concentrations. The explanation of this phenomenon involves the complex pattern of water movement created by the vertical mulch. At high rainfall intensities, large quantities of water were diverted away from and

TABLE 1.—Average nitrate concentrations at sites where at least one treatment variable resulted in significant differences
[Parts per million of NO_3^- -N]

Sampling position (X,Y)	Treatment							
	$b_0m_0r_0$	$b_0m_1r_0$	$b_0m_0r_1$	$b_0m_1r_1$	$b_1m_0r_0$	$b_1m_1r_0$	$b_1m_0r_1$	$b_1m_1r_1$
HIGH-INTENSITY RAINFALL (EXPERIMENT 1)								
0,—2	746.0	3,547.0	929.0	1,887.0	413.0	300.0	256.0	126.0
0,—4	636.0	1,313.0	191.0	1,090.0	10.9	19.1	7.6	16.6
0,—6	404.0	609.0	81.0	517.0	5.4	10.4	7.3	17.8
0,—8	261.0	552.0	360.0	352.0	6.8	6.0	6.5	16.6
0,—12	240.0	533.0	307.0	112.0	6.2	15.2	6.7	25.3
0,—16	418.0	270.0	228.0	105.0	4.8	21.9	5.9	34.6
0,—20	559.0	111.0	406.0	133.0	6.3	44.7	8.9	57.4
0,—24	376.0	89.0	359.0	48.3	30.9	62.8	14.1	29.0
2,0	44.3	226.0	209.0	1,501.0	31.1	549.0	145.0	113.0
—2,0	24.8	824.0	31.2	80.6	178.0	44.0	218.0	90.4
LOW-INTENSITY RAINFALL (EXPERIMENT 2)								
0,—2	2,644.0	2,617.0	1,896.0	2,458.9	76.7	31.4	32.5	89.2
0,—4	762.0	957.0	618.0	819.0	8.3	11.8	7.2	7.0
0,—6	573.0	595.0	543.0	666.0	10.6	6.7	8.2	7.3
0,—8	400.0	378.0	405.0	535.0	9.2	8.3	7.6	6.1
0,—12	324.0	371.0	311.0	539.0	7.2	7.2	6.0	6.9
0,—16	839.0	438.0	347.0	559.0	7.9	9.4	5.1	7.0
0,—20	641.0	343.0	489.0	821.0	11.4	7.8	7.9	23.1
0,—24	292.0	207.0	517.0	600.0	38.2	13.8	12.1	26.1

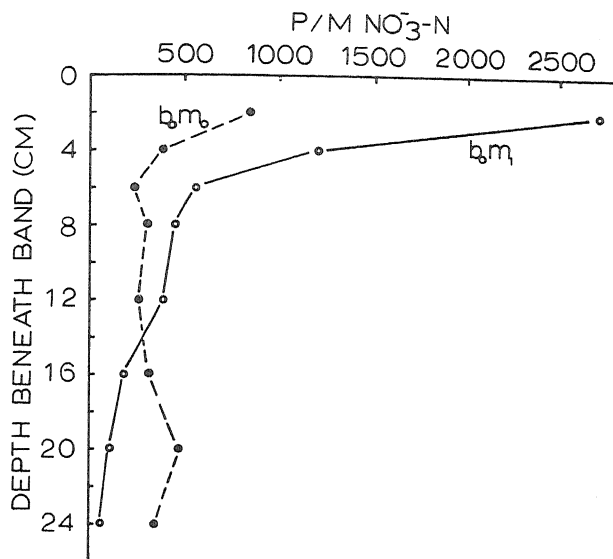


FIGURE 2.—Average nitrate concentrations at depths beneath a standard band combined with a vertical mulch (b_m) and without a vertical mulch (b_{m0}).

below the band. Water moved from the mulches inward towards the Y-axis before moving downward through the standard band. Since less water moved through the fertilizer and down the Y-axis, one would expect greater nitrate concentrations at the upper levels and less leaching down into the profile. In the absence of a mulch, more water moved directly through the standard band, carrying nitrates to lower depths. Apparently, vertical mulches retard nitrate leaching from standard bands.

The influence of the various treatments on plant growth is equally as important as their influence on nitrate leaching. Table 5 shows the average dry weight and total nitrogen content of corn tops and roots. The standard-band treatment always resulted in the largest, but not necessarily significant, dry weight and nitrogen content. Coarse-band dry weights 2 weeks after plant emergence were inconclusive. However, while the total nitrogen contents of the roots and tops from both band treatments were significantly greater than the check, there were no significant differences in the nitrogen contents between the two treatments. During the 2-week period, while plant needs were minimal, the two band treatments seemed equally effective in supplying the necessary nitrates. On dismantling the boxes, it was observed that roots had entered the outer fringes of the coarse band but had not grown into the center of the band.

Figure 3 shows the 2-week nitrate concentrations at various depths beneath the bands. The high uniform concentration beneath the standard band showed that nitrates had moved freely into the profile with the water. The coarse band showed a high concentration at 4 cm, which decreased with depth until it approached check concentrations. Nitrate leaching from the coarse band had just started and obviously lagged behind that from the standard band.

TABLE 2.—Treatments and levels of significant difference in nitrate concentration at various sites in the soil profile

Sampling position (X,Y)	Treatment											
	B		M		R		BM		BR		MR	
	L	H	L	H	L	H	L	H	L	H	L	H
0,—2	**	**	...	*	*
0,—4	**	**	...	*	*
0,—6	**	**	...	*	*
0,—8	**	**
0,—12	**	**
0,—16	**	**
0,—20	**	**	**
0,—24	**	*	*
2,0	*
—2,0

** Significant at 0.01 level.

* Significant at 0.05 level.

B Coarse-textured fertilizer band. M Vertical straw mulch. R Surface ridges. L Low-intensity rainfall. H High-intensity rainfall.

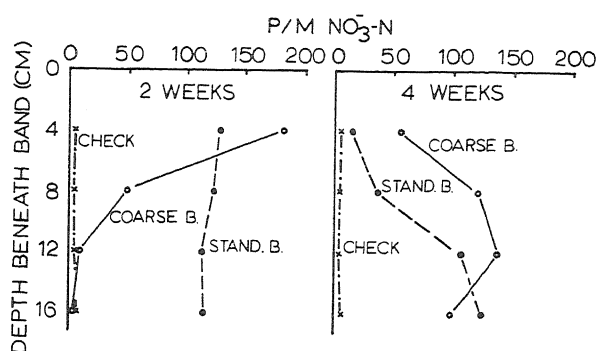


FIGURE 3.—Average nitrate concentrations beneath fertilizer bands 2 and 4 weeks after corn emergence.

Four weeks after plant emergence, dry weights of plants from the coarse-band treatment did not significantly differ from the check; both were significantly less than the standard treatment (table 5). However, the total nitrogen content of the tops from the coarse-band treatment was significantly higher than that of the check treatment, with a concentration three times higher, but it did not differ significantly from the standard treatment.

The standard band root-nitrogen content was also significantly higher than in the check and coarse band treatments. While the coarse band nitrogen content was almost twice that of the check, it missed significance at the 0.05 level by less than 0.1 milligrams N.

The 4-week soil nitrate distribution (fig. 3) shows definitely that nitrates had moved from the coarse band into the profile where they were available to plants. This was visually evident when plants from the coarse-band treatment as-

sumed a deeper green coloration a few days prior to harvest. Figure 3 also shows that nitrates from the standard band had moved further down into the profile, since the concentration at 4 cm approached that of the check.

It is apparent that nitrates from the coarse-textured band were available to plants at 4 weeks after emergence. Root development at this stage was sufficiently extensive to intercept the nitrates. The data indicate that nitrates in small amounts were available to roots earlier, since plant nitrogen content exceeded that of the check. Since the plant nitrogen content and dry weight of the coarse band lagged behind the standard-band treatment at the 4-week stage, indications are that the rate of nitrate release from the coarse band was not equal to the plant uptake potential.

One can only speculate on the relative plant growth and nitrogen uptake had the plant experiment continued for a longer time period. Since nitrates were available and the root systems were well developed at 4 weeks, it could be assumed that, given sufficient time, the yields from both band treatments would be similar.

The engineering aspects of a coarse-textured band treatment in the field were not considered in this study. The coarse-band influence would not be confined to gravels alone; any coarse material which provides an abrupt textural discontinuity should be effective. Because of their availability, crop residues may prove the most logical choice. Crop residues could further reduce leaching by immobilization of the nitrates.

TABLE 3.—Average nitrate concentrations influenced by the fertilizer band only
[Parts per million of $\text{NO}_3\text{-N}$]

Treatment	Sampling position (X,Y)							
	0,—2	0,—4	0,—6	0,—8	0,—12	0,—16	0,—20	0,—24
HIGH-INTENSITY RAINFALL (EXPERIMENT 1)								
b_0	.....	.....	.....	382.0	298.0	255.0	.....	.....
b_1	.....	.....	.....	9.0	13.4	16.8	.....	.....
LSD _{0.05}	.....	.....	.....	114.0	127.0	83.7	.....	.....
LOW-INTENSITY RAINFALL (EXPERIMENT 2)								
b_0	2,404.0	789.0	594.0	430.0	398.0	546.0	574.0	404.0
b_1	57.5	8.6	8.2	7.8	6.8	7.4	12.6	22.6
LSD _{0.05}	368.0	168.0	109.0	77.9	93.8	222.0	188.0	205.0

LSD_{0.05} Least significant difference at 0.05 level.

TABLE 4.—Average nitrate concentrations influenced by fertilizer band-mulch interactions¹
[Parts per million of NO₃-N]

Sampling position (X,Y)	Treatment			
	b_0m_0	b_0m_1	b_1m_0	b_1m_1
0,—2	834.0a	2,716.0b	333.0a	213.0a
0,—4	394.0a	1,201.0b	9.2a	17.8a
0,—6	243.0b	563.0c	6.4a	14.1a
0,—20	483.0b	122.0a	7.6a	51.1a
0,—24	368.0b	68.6a	22.5a	45.9a
—2,0	28.0a	452.0b	198.0ab	67.8a

¹ Means not having a letter in common are significantly different at the 0.05 level by Duncan's multiple-range test.

TABLE 5.—Dry weight and total nitrogen content of corn tops and roots as influenced by fertilizer treatment¹

Harvest and analysis	Fertilizer band		No fertilizer (check)
	Standard	Coarse-textured	
2 weeks:			
Tops:			
Dry wt (grams)	0.76a	0.72a	0.47a
Milligrams N	27.8a	23.4a	10.9b
Roots:			
Dry wt (grams)	0.50a	0.34ab	0.26b
Milligrams N	7.4a	7.0a	3.8b
4 weeks:			
Tops:			
Dry wt (grams)	3.61a	1.95b	1.40b
Milligrams N	94.0a	60.1a	20.7b
Roots:			
Dry wt (grams)	2.24a	0.97b	0.99b
Milligrams N	30.5a	17.4b	8.8b

¹ Means not having a letter in common are significantly different at the 0.05 level by Duncan's multiple-range test.

CONCLUSIONS

Nitrate fertilizers, when banded within coarse-textured materials, moved down into the soil profile at a slower rate than nitrates from standard bands. The water initially moved around the band, leaving the fertilizers nearly intact. Other treatments such as vertical straw mulches and surface ridging had no influence on the coarse band. However, vertical straw mulches with standard bands, at high rainfall intensities, re-

duced nitrate leaching by diverting water away from the band. Surface ridging did not influence leaching from the standard bands. Under irrigated corn, coarse-textured bands effectively retarded nitrate leaching from the standard bands after plant emergence. At plant emergence, nitrates moved down into the soil profile at a slower rate than nitrates from standard bands. However, vertical straw mulches with standard bands, at high rainfall intensities, re-

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